

# Metals Additive Manufacturing

Great Promise in Mitigating Shortages but Some Risks Remain

Drew Miller ■ Ed Morris ■ Greg Colvin

**A**dditive manufacturing (AM) is revolutionizing the way parts are designed and manufactured, shrinking development and delivery cycle times, and yielding improved performance at a lower cost per part.

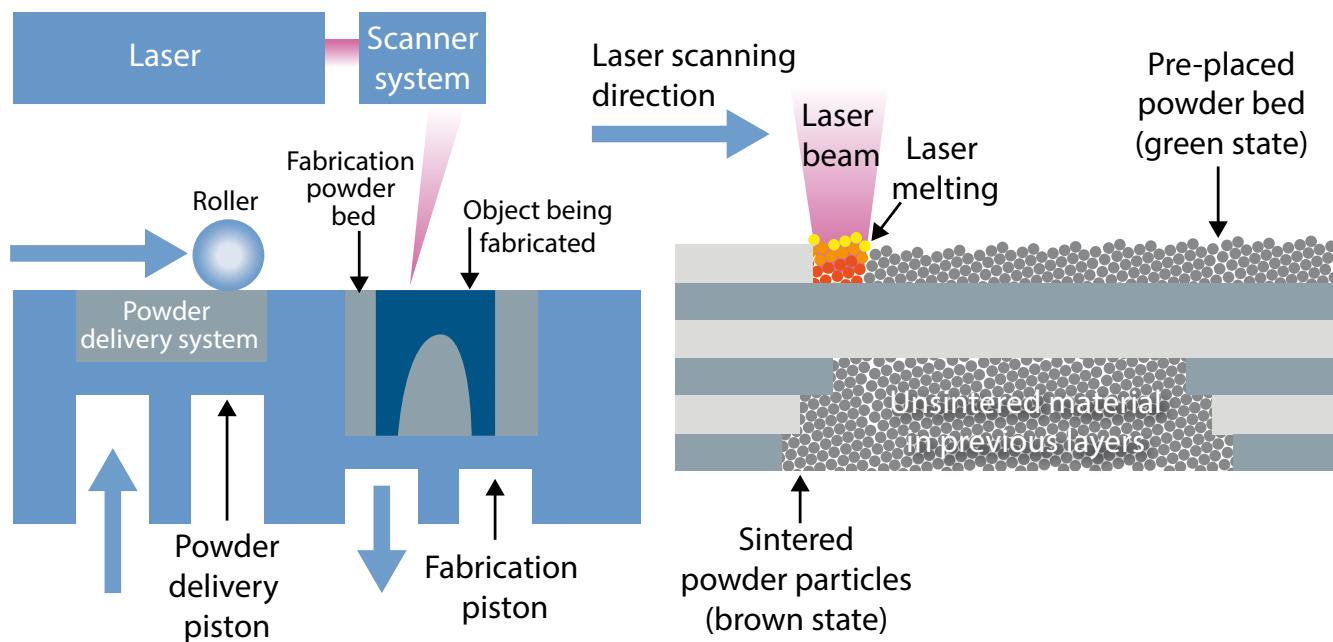
Shapes previously not possible and that have tailored properties and material compositions, can be produced on demand for specific military devices and platforms. AM's potential to provide real-time rapid response support to the warfighter may be unparalleled in our time relative to conventional manufacturing methods.

But while AM can help deal with Diminishing Manufacturing Sources and Material Shortages (DMSMS) problems, many experts interviewed for a recent report on research and development (R&D) advances impacting DMSMS warned that "AM is highly overrated." It is limited in what it can offer and poses some risks for obsolescence management. As we leverage the growth of this new technol-

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**Figure 1. The Powder Bed Metal Fusion Additive Manufacturing Process**



ogy, it will be critical for the Department of Defense (DoD) acquisition and sustainment practitioners to understand its benefits but also risks, challenges and maturity level as they consider AM for solving DMSMS challenges.

The DoD has been an active partner with the industrial base supporting AM through initiatives such as establishing "America Makes"—the National Additive Manufacturing Innovation Institute—and funding some AM-related Manufacturing Technology (ManTech) programs. Many of the DoD efforts in AM have concentrated on tooling and newly designed never before produced complex parts. However, due to its versatility and rapid response, AM may be uniquely suited in supporting sustainment requirements especially for DMSMS situations.

One AM technology of interest is using metal powder to create a part. Generally speaking, "Powder Bed Metal Fusion" AM processes are a "mini-melt" welding approach during which a computer-controlled laser or electron beam is moved over a bed of powder, fusing or sintering the powder selectively to make a part. As illustrated in Figure 1, after each pass, a new layer of powder is laid down using a recoater blade and the process continues until thousands of layers have been sintered to make the desired configuration. The resultant parts, although quite detailed in geometric complexity, still require secondary processing to be suitable for mechanical system application.

### AM Challenges and Applications

As noted in a 2015 Government Accountability Office report, a "key challenge" to the DoD community for AM is "ensuring that manufacturers can repeatedly make the same part

and meet precision and consistent performance standards." For quality comparison purposes, forging, rolling and traditional metal manufacturing and processing yield consistent, well-characterized properties and predictable processing responses.

The characterization and understanding of the materials properties for AM-produced components is at the very beginning stages. So far, AM-produced metals have had surprisingly strong mechanical properties yet their behaviors do not fit traditional metal processing behaviors. This is a serious constraint for DoD where repeatable strength, weight and highly reliable quality are critical. Experts estimate it may take a decade to achieve confidence and certification for some AM metal applications.

Because of the tremendous variation possible in AM metal fabrication which in effect involves thousands of "mini melt pools" in a single part, there is a larger potential for variability and property problems, especially if real-time in-situ process controls are not employed. For example, when industry develops a new alloy, even for well-proven traditional production processes, it can take more than 5 years and several million dollars to qualify the alloy. Metal AM with more variability and less experience likely will take longer.

Significant government-sponsored efforts have supported the AM community in developing consistent repeatable manufacturing processes. As an example, the National Institute of Science and Technology (NIST) is funding research to provide quality assurance of AM parts. The DoD Metals Additive Manufacturing Qualification and Certification Working Group

is developing standards and processes for material, process and product qualifications for AM.

AM is used for both metal and polymer parts. AM with polymers involves lower-risk applications and benefits from ongoing advances in polymers, so there are generally fewer problems with variances in material properties and greater near-term potential for DMSMS applications where the structural strength of a metal is not required.

The need to certify AM applications poses less challenges for tooling and prototype and development hardware applications. For replacing obsolete parts, polymer and metal AM has been estimated to be feasible for 5 to 10 percent of demand within the next 10 years. AM is an especially good means for making low-quantity, complex metal castings (with the caveat of unsmooth surface issues in some applications), such as the one shown in the photograph. The Agile Manufacturing Center for Casting Technologies at the Naval Undersea Warfare Center (NUWC) Keyport in Washington state can make castings faster and cheaper with AM. They can often be made better as well, though there are size limits with current AM machines. AM currently best fits very low volume production—such as replacing a few obsolescent parts or castings and building prototypes. In addition, AM is used to create special tooling in lieu of machining and assembly; AM also eliminates the need for storage. In all of these AM applications, NUWC Keyport has achieved order of magnitude improvements in cost and schedule.

Similar successes were obtained by the America Makes-funded project led by the Youngstown Business Incubator (YBI) that focused on accelerating the adoption of AM in the U.S. foundry industry. YBI assembled a large project team consisting of the American Foundry Society, Northern Iowa University, ExOne, Caterpillar, Humtown Products, Trumbull, XL Pattern Shop, Danko Arlington, Hoosier Pattern Inc., REFCOTEC Inc., and Product Development Analysis, and it produced the following equally large results:

- Reduced cost of materials for printed sand molds and cores by more than 80 percent.
- Increased speed to market: 3 weeks versus 12 or more weeks.
- Increased affordable quantities for three-dimensional (3D) sand printing of simple castings by 50 percent.
- Enabled part optimization for improved performance.

Significant workforce training now is under way to spread the project findings across the U.S. foundry industry.

AM to date has been particularly successful in commercial industry for General Electric's jet engine fuel nozzle where a high-value, sophisticated component lends itself to combining multiple components and eliminating joints and cost. While subject to high heat stress, it has relatively little physical stress and, therefore, few certification requirements. Where a single metal AM-produced part can replace multiple complex parts, it can be economical for high-volume production to supply low physical stress situations. GE Aviation plans to produce more than 100,000 AM-produced fuel nozzles by the year 2020 for its LEAP engine.

Some AM advocates have suggested deliberately abandoning large production runs and stockpiled inventories. The Defense Logistics Agency (DLA) lists AM as a priority in its R&D Strategic Directive. In a 2015 slide presentation, 3D printing is featured with the notation, "Store data, not parts." In the long term, we may be able to reduce spare part production and inventory as an effective solution for DMSMS and life-cycle cost effectiveness. This will not be feasible in the near term for it will still be cheaper to mass produce and store inventories of the vast majority of parts through traditional manufacturing. Furthermore, because AM technology evolves very rapidly, technical data formats change as well. This potentially means the technical data will be unusable if not properly maintained and updated.

There is a risk that many programs may decide not to mass produce backup parts in favor of easily printing them later to save money up front on new systems. This approach for spares is only practical if the original part is made using AM.



**A sample 3D printed sand mold and the resulting cast part from America Makes project led by the Youngstown Business Incubator.**

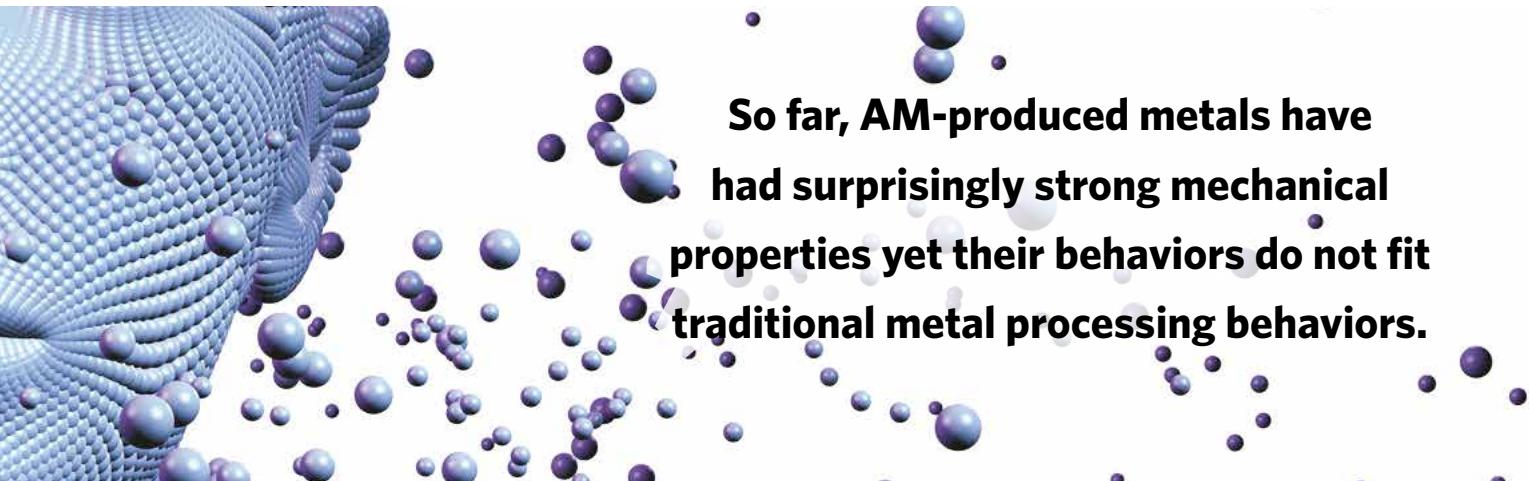
Photo courtesy of The ExOne Company

Otherwise, the temptation for program managers to cut spares for traditionally manufactured parts will generate downstream life-cycle cost problems for sustainment, especially if the cost savings of traditional mass production of spares during production are significant and re-engineering and qualification testing are required for the AM-produced spare part.

Another risk is that AM for DMSMS may increase the risk of encountering counterfeit problems. The fact that an AM metal or polymer part may look the same, but have far different properties and potentially much lower strength and durability may yield another big realm for dangerous counterfeit parts. They may contain cheap internal material, with the proper material

scrapped due to inactivity or the manufacturer is no longer in business. Replacement of casting and/or forging tooling often requires months and significant upfront investment. AM provides unique value via its rapid response, geometric flexibility and lack of specialized tooling relative to other typical manufacturing options. For example, the AV-8B Hard Landing and Repair C-Channel Brackets repair was done in 1 week with 3D solid computer-aided design modeling and AM.

A third common DMSMS scenario occurs when required delivery schedules are unachievable using conventional manufacturing. Unachievable schedule requirements to produce and deliver products are a common cause of no-bids from



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just a coating, or there may be voids and defects. The low investment requirement for AM production versus traditional metal manufacturing also means it is cheaper and easier for counterfeiters to become involved. DoD production of fewer spares in favor of later AM production of replacement parts also would increase the risk that we will be offered counterfeit or substandard parts.

### DMSMS Scenarios for AM

DoD acquisition and sustainment practitioners have successfully leveraged AM as a viable option for solving DMSMS obsolescence issues.

One common root cause for DMSMS is a low purchased part count relative to normal conventional manufacturing quantities. Conventional manufacturing processes such as casting and forging are designed to produce large numbers of parts. When the DoD requires smaller quantities (e.g., fewer than 100) the nonrecurring engineering expense of starting up a casting or forging process is often significant, driving up the part's unit price. AM is particularly suited to these situations as one of its core competencies is its ability to make parts without dedicated direct-to-shape tooling.

Another frequent DMSMS scenario is when the original production tooling is no longer available. This situation may arise because the tool wore out during normal production, was

vendors. AM's rapid response capabilities are unparalleled in other manufacturing processes. For example, the Navy recently needed a circuit card clip for the J-6000 Tactical Support System Servers that is installed onboard Los Angeles-class nuclear submarines and Ohio-class nuclear-powered guided-missile submarines. Learning that the clip is no longer produced by its original manufacturer—NUWC—Keyport used AM to create a supply of replacement parts to keep the Fleet ready.

### AM Readiness for Shortage Management

What is the "state of the art" regarding AM? Note that this discussion lumps together all metals AM such as Selective Laser Melting, Laser Cutting, Direct Metal Laser Sintering and Electron Beam Melting (EBM) and collectively refers to them as "Powder Bed Metal Fusion."

When considering AM for potential sustainment and DMSMS opportunities, the availability of the AM raw materials is important. Powder for AM currently is available in a few standard alloys such as titanium (Ti-6Al-4V), Nickel Superalloy (IN718), and stainless steel (304). There are a number of common casting, forging and extrusion and plate stock alloys not available in powder forms suitable or proven for use with AM. As an example, powder feedstock for very common aluminum alloys such as 6061 are not yet proven for either raw material supply or AM Metal Powder Bed Fusion processes. In summary, those

considering AM should start with asking the question, "Is the metal we want to make the parts from available in AM?"

Next the practitioner must determine if their particular alloy has been developed and characterized for AM. Note that significant work has been sponsored by the DoD and commercial industry to develop AM processes for several important materials used in military applications, including nickel based alloys IN718, iron-based 304 stainless steels and 17-4ph stainless steel. However, AM processes have not been developed for many common casting and forging alloys. Those considering AM as a DMSMS solution must determine if AM processes have been developed for that specific alloy.

Assuming these first two criteria have been met, the practitioner next must determine if AM can produce the shape required. One of AM's "best in class" attributes is its geometric capabilities. AM has unparalleled abilities to produce a custom product, with complex internal shapes not producible via traditional, subtractive processes. There are limitations however, such as size. Currently "Metal Powder Bed Fusion" has a maximum commercially available machine size—a 15-inch cube. A larger part would require manufacturing individual sections joined together using a process such as brazing or welding—or changing to an alternate AM process that can accommodate larger metal parts.

Another question is affordability. The AM process cost depends on parameters too numerous to illuminate fully in this article. One significant cost driver is the required quantity of parts. Lower output numbers favor AM as the process does not demand the upfront investment in tooling and engineering relative to traditional metals manufacturing processes. Conversely, larger part quantities tend to favor traditional manufacturing processes. Other critical cost factors are part material type and the final part weight versus the raw material required—both factor into the yield calculation (weight of produced parts versus overall material usage). A third factor is part shape. The greater the number of parts that can be built at once through AM, the less expensive the per-part cost. If the part is shaped and sized in such a manner that multiple parts can be fit into a single build then the per-piece price is reduced. DLA projected cost savings of 33 percent to 50 percent for AM casting of core tooling of airfoils (blades and vanes).

Properly managed, AM will play an increasingly important role in DMSMS resolutions. The risks of AM, including new counterfeit threats, especially for metal, need to be anticipated and mitigated. The quality control and certification problems with metal AM must be resolved. AM should not be used as an excuse to avoid upfront large spares purchases or life-of-need buys unless the original part already is additively manufactured. 

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